5-1948

Crop Response to Applications of Coopper Sulfates on Salty Soils

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CROP RESPONSE TO APPLICATIONS OF COPPER SULFATE

ON SALTY SOILS

by

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A thesis submitted in partial fulfillment
of the requirements for the degree

of

MASTER OF SCIENCE

in

SOIL SCIENCE

1948

UTAH STATE AGRICULTURAL COLLEGE
Logan, Utah

ACKNOWLEDGMENT

I express my sincere appreciation to President F. S. Harris for making this research on copper available to me, to Dr. D. W. Thorne for his patience and constant help and guidance, and to the members of my committee, Dr. Sherwin Maeser, Dr. F. B. Wann, Professor D. C. Tingey, and Professor I. B. Hayward, for their suggestions on my thesis. I also wish to acknowledge the pains-taking work of Mrs. S. L. Waldee in typing my thesis.

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INTRODUCTION

In the arid west large areas of soil contain soluble salts in sufficient concentrations to inhibit crop growth. Of the 1,416,957 acres of soil surveyed in Utah from 1899 to 1920, Jennings et al (29) reported that 43.58 per cent contained 0.2 per cent or more of salts. The management and reclamation of these soils present serious problems. The difficulties are further accentuated by the fact that many streams used for irrigation contain appreciable quantities of salt. Generally under these conditions removal of the salt from the soil becomes impracticable, and the problem is one of learning how to get along in spite of the salt.

An early study by Lipman and Gericke (34) and some preliminary tests at the Utah Agricultural Experiment Station have indicated that crops growing on salty soils may be benefited by applications of copper salts. Because of the economic importance of any procedure for increasing crop production on salty soils, additional studies were proposed to further investigate the problems involved.

The research on this problem was planned to investigate the value of copper sulfate in increasing crop yields on salty soils and to study ways in which copper might benefit plants under these conditions. Further studies were planned to determine whether an antagonism can be produced in saline soils between sodium chloride and copper sulfate and to

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*The costs of this study were supported in part by a grant from the Utah Copper Company.

determine whether this antagonism is specific for copper or whether it might also be produced by other ions.

LITERATURE REVIEW

Uses of copper

The use of copper sulfate as a soil amendment has become an established practice on soils of certain characteristics in many places. Decided crop responses, both in growth and quality, have been reported in the organic soil areas of the United States (1)(16)(17)(41) and Europe (27) and in the coarse-textured calcareous soils of Australia (52)(55). Copper, especially since the proof of its essential nature was demonstrated in 1931 (36)(58), is recognized as the treatment for "reclamation disease" of field crops and "exanthema" or "dieback" in fruit trees. To correct the deficiencies copper is usually applied directly to the soil, but spray treatments and injections have also given satisfactory results.

Reports of experiments at the Brigham Young University and at Magna (19)(20) showed a small crop response from copper treatments to the soil; however, an analysis of the data presented suggests that the increases in yield are not statistically significant. Field trials at the Utah Agricultural Experiment Station indicated that copper deficiency is not a problem in Utah. For these reasons, other uses of copper have been under investigation. Willis (66) suggested that minor elements, including copper, may be beneficial in areas where there are no deficiency symptoms. He stated that in the podzolized soils, in general, there is evidence that copper is needed in soils which fail to respond to the application of superphosphate, and in soils which have a great need for potassium. Lipman and Gericke (34) in California obtained response to applications of copper sulfate to barley grown in artificially-salinized soils. They attributed this response to antagonism between copper sulfate and sodium chloride. This is probably the only account in the literature of response to copper salts on saline soils, but the literature is replete with reports on the antagonism of ions.

Antagonism

When the application of one ion suppresses the absorption of other ions, creates a better environment for plant growth independent of fertilizer effects, or in other ways results in increased yields, the phenomenon is termed antagonism. Several theories have been advanced to explain antagonism, among which are the following:

1. A theory somewhat analogous to Liebig's "Law of the Minimum" was developed by Loeb (36)(37). He showed that solutions of single salts were toxic to fish eggs and young fish, but that fish lived for long periods of time in distilled water or mixtures of salts in the proper proportions. This theory may be called the balanced solution theory. The work of Osterhout (47)(48)(49) substantiated Loeb's theory. Osterhout developed the hypothesis that salts in balanced solutions penetrate cell membranes more slowly than in unbalanced solutions. He assumed that antagonistic salts combine with some constituent of the protoplasm. Loeb (38)(39) in his work with gelatin and protein found that antagonism may be due to the formation of metal salts with the protein. Antagonism could be brought about when a univalent cation is replaced with a bivalent cation. The gelatin salt of the univalent metal was apparently dissociated to a greater degree than the salt of the bivalent metal. In

earlier work (36)(37) he found that the toxic effects of monovalent ions could be prevented with di- or tri-valent ions. In an experiment with starfish eggs, Lillie (33) suggested that calcium forms solid, water insoluble colloidal salts with the structural colloids, while sodium salts are soluble.

2. Barton-Wright (5) stated that the most probable explanation of antagonism is that the proteins of the protoplasm absorb salts in definite proportions, and unless absorbed in definite proportions, the proteins are not active.

3. Thomas (61) stated that with binary mixtures of alkali and alkaline earth salts having a common anion, maximum antagonism occurs when the concentration of each salt is that which if separately dissolved in the same volume of water as that of the mixture, would give the same ionization coefficient. The antagonistic action is greatest at that particular concentration of ions represented by the intersection of the dissociation curves of each salt separately determined at dilutions corresponding to the proportions at which each salt is present in the mixture. Antagonism is nil when the dissociation constant of the mixture is unaltered.

4. Antagonism may result from the depression of the solubility of one ion by the addition of another ion, as in the case reported by Thomas (61) where the addition of lime depressed potassium uptake.

5. Some ions are absorbed more slowly than others. The rate of absorption in the pH range 5.5 to 7.0 as given by Thomas (61) in decreasing order is: H, K, Na, Li, Mg, Ba, Sr, Ca for cations; and for anions, OH, $\frac{Bi}{I}$, NO_3, Cl, HPO_4, and SO_4. The addition of a slowly absorbed ion in sufficient amount would decrease the rate of absorption of any ion

associated with it (25).

6. Hurd-Karrer (28) suggested that one type of antagonism could be explained on the basis of a certain degree of unselectivity of ion absorption on the part of plants. When the nutrient ion is not available in sufficient quantity, the plant uses a chemically related toxic ion. Hurd-Karrer found that arsenic injury is a function of the available phosphate concentration, rubidium injury is a function of the available potassium concentration, and strontium injury is a function of the available calcium concentration. In nutrient solutions the protective ratios for arsenic to phosphorus, rubidium to potassium, and strontium to calcium were respectively 1:5, 1:2, and 1:1. She termed this type of antagonism "mass antagonism".

Osterhout (50) reported that in solutions antagonistic action decreased with dilution. These results are supported by Pierre and Bower (51) who stated that "ion competition" is more pronounced at high concentrations than at low. Thomas (61) stated that the solution cultures used in studying antagonism are 5 to 20 times as concentrated as the soil solution.

Examples of antagonism are very numerous. Besides those already mentioned, the following are submitted. Moxon and Wilson (45) found that arsenic fed through the drinking water reduced the toxicity of selenium in grain fed to chickens. Sutter (60) reported antagonism between copper salts and thyroxine in tadpoles, but copper soon became toxic. Waksman and Johnstone (64) showed that the addition of copper salts to sea water media first depressed bacterial development, but later stimulated growth.

The beneficial results from keeping a proper balance between calcium and magnesium, calcium and boron, and manganese and iron are discussed extensively in the literature.

Plant relations on salty soils

"A saline soil may be defined as one which contains sufficient soluble salts to impair its productivity" (56). The characteristics of a saline soil are as follows (56): The exchangeable sodium is less than 15 per cent of the exchangeable cations. The pH is usually less than 8.5, and the conductivity of the saturated extract is more than 4 millimhos/cm. Sodium seldom comprises more than half the soluble cations, so is not appreciably absorbed on the clay. The anions are chiefly chloride and sulfate, however nitrate sometimes occurs in appreciable concentration. Bicarbonate may occur in small amounts, and carbonate is present in low concentrations. The carbonates of magnesium and calcium may be present as insoluble salts.

The establishment of limits above which the salt content of the soil is excessive would be very valuable, but is difficult. The salt content of the soil at which plants are affected depends upon the type of soil, the nature of the salt, the plants growing in the soil, and the climatic factors. Normally fertile irrigated soils as reported by Magistad and Reitemeier (43) had a solution concentration sufficient to exert 1.3 to 1.8 atmospheres osmotic pressure at the wilting percentage. Good growth was obtained where the osmotic pressure did not exceed 4 atmospheres. When the osmotic pressure at the wilting percentage reached 10 atmospheres, plant growth was limited, and above 40 atmospheres nothing would grow. In the field, salt relationships are complicated since plants may be growing in soil high in salt at or near the surface, yet drawing moisture from a relatively non-saline subsoil. Two factors make up the stress on the water in the soil. These factors are (a) the osmotic pressure caused by salts and (b) the force of attraction between the soil particles and the water. Under non-saline conditions, plants wilt at fairly definite soil moisture values, but this is not true of plants on saline soils. The moisture stress in a saline soil develops more uniformly allowing the plant to make adjustments. Plants, though suffering for water do not appear dry. The establishment of a limit between saline and non-saline conditions is further complicated by the fact that there is no sharp change in soil properties, as the degree of salt saturation increases. The adverse conditions develop gradually (56). Different arbitrary limits have been set up between saline and non-saline soils: Kellogg of the Bureau of Chemistry and Soils (31) established 0.2 per cent salt as the limit, while Kearney and Scofield (30) set 0.1 per cent.

In general salts in soils affect plants in two ways: (a) directly, through osmotic pressure and through toxicity of certain ions, and (b) indirectly, through the salt effects on soil structure and permeability, with resultant effect on aeration. The osmotic pressure created by the dissolved salts varies with the nature and concentration of the salts and the soil characteristics. In any soil the limit of the solution concentration as far as the plant is concerned is the wilting percentage (42). Plants usually die when the total stress reaches about 15 atmospheres. Secondary effects in the soil may result when sodium becomes excessive and the soil becomes dispersed or puddled. This is especially true in heavy soils. In alkali soils where the exchange complex becomes more than 40 to 50 per cent sodium saturated, nutritional disturbances result whereby calcium may be removed from the plant tissues of the root and the plant die from calcium deficiency (56). In addition, plants suffer from lack of soil aeration. Boynton, *et al.* (7) reported that with apple trees, the roots are at a subsistence level when the oxygen in the soil moisture is at 3 per cent. At oxygen levels below 1 per cent, the roots lost weight, between 3 to 10 per cent the root tips grew, while over 12 per cent oxygen new roots formed.

Plant symptoms of salt injury are generally hard to distinguish, owing to the fact that reduced growth is usually the only effect that is apparent. Symptoms are described (56) as stunting of growth and deep blue-green color of leaves. Cereals may show reddish coloration in the presence of chlorides. Magistad and Christiansen (44) stated that peaches showed chlorosis, tip burn, and dieback in the presence of high concentrations of chlorides. Beans were observed to show leaf tilting as they do in dry conditions. In saline soils, some plants may develop wax coating on the leaves.

Early investigators stressed the toxic effects of ions and spoke of "limit of endurance" (8) and "toxic limits" (18). These terms reveal the dominant thought until the early 1930's that neutral salts below certain concentrations did not affect plant growth, but if concentrations exceeded these limits plant injury was pronounced (10). Recent work points to the probability that concentrations of salt merely reduce growth (4)(9)(10)(12)(13)(44). Studies indicate that growth reduction is a linear function of the concentration of the substrate in which the plant is growing. Salt sensitive crops have a steeper sloping line than salt tolerant plants (43). In general, growth is reduced as the osmotic pressure increases over 2 atmospheres (10). "At concentrations less than

2 or 3 atmospheres the nature of the salt and ratio of one ion to another in the soil culture solution may affect plant growth more than does the total concentration in atmospheres" (44). In an experiment performed by Gauch and Magistad (12), alfalfa in sand cultures was reduced in yield about 10 per cent for each increase of 1 atmosphere of osmotic pressure. Yields of the legumes in the experiment were inversely proportional to salt concentration. "There was no evidence that there is a given concentration of solution which may be regarded as critical, but rather there tended to be a linear relationship between growth reduction and increase in salt concentration of the solutions as expressed in atmospheres." In sand cultures, Eaton (10) showed that there was no abrupt toxicity point, but above a certain minimum the retardation in growth became less with each increment of concentration. He suggested that reduction in growth in saline conditions is due to a slower uptake of nutrients which slows root development resulting in less penetration and smaller supply of nutrients to the plant.

In addition to growth reduction, under certain conditions some ions are more toxic than others. Hayward and Spurr (24) in sand cultures using sodium chloride, calcium chloride, and sodium sulfate in osmotic concentrations of 1.5 to 4.5 atmospheres found that with flax, growth was about equal at equivalent concentrations, except for the highest concentration, where growth inhibition was more pronounced in the sulfate cultures. Gauch and Wadleigh (13) growing kidney beans in aerated nutrient solutions containing added salts (sodium sulfate, sodium chloride, calcium chloride, magnesium chloride, and magnesium sulfate) in osmotic concentrations of 1.5 to 4.5 atmospheres obtained approximately the same growth at the same concentrations in all but the magnesium salts, which produced marked growth depression. Magistad and Christiansen (44) reported that at high concentrations, sodium, calcium, and magnesium were about equal in toxicity, but in lower concentrations, calcium was usually least toxic and magnesium was most toxic. Specific ions may be more toxic to certain types of plants (56). These ions include carbonate, borate, and in special cases sodium, magnesium, and chloride.

The toxicity of sodium in soils may be due to the fact that the soil is unable to furnish adequate calcium even though calcium carbonate is present (6). Ratner (53) reported that in a Chernozem artificially made Solonetz, a sodium percentage of 71 per cent of the exchangeable bases was fatal to plants even though they were well supplied with nutrients and the soil was diluted 6 times with sand. He stated that sodium may cause death due to a breakdown of the calcium regime. Thorne (62) found that the calcium content of plants decreased as the exchangeable sodium in a synthetic soil increased. Reed and Haas (54) showed that roots of citrus seedlings in pure sodium chloride solutions did not develop because of calcium starvation. Long (40) found that sodium chloride concentration reduced the uptake of water and nutrient ions--calcium, potassium, and nitrate. Hoagland (25) reported that high sodium depressed the absorption of other cations.

Toxicity is produced in other ways. Nightingale and Farnham (46) found that high concentrations of nutrient salts produced low protein synthesis in sweet peas.

The effects of salt on water absorption are similar to subjecting the plant to drouth. As the osmotic pressure of the soil solution increases, water absorption proceeds at a slower rate (42). The cell accommodates itself by increasing its own osmotic concentration. Hayward and Long (23) using solution cultures varying from 0.5 to 4.5 atmospheres osmotic pressure found that the osmotic concentration in the cell sap of tomatoes increased with increased solution concentration. The limits of osmotic pressure found in the cell sap of agricultural plants is 10 to 20 atmospheres (42) while the cell sap of salt tolerant plants growing in salty soil may reach as high as 150 atmospheres (21). Recent studies (10)(24)(44) showed that as the osmotic pressure in the substrate increases, water entry into the plant decreases. Eaton (9) reported that osmotic pressure rather than specific ion effects is primarily involved in water uptake.

The quantity of an element absorbed by a plant bears no relation to the water absorbed (40), but depends upon plant growth, concentration of solution, and the nature of the ions. Hoagland (25) showed that water and ions are seldom removed from the solution in the same proportions as they exist in the solution. He found that the rate of absorption of ions was greatly influenced by the nature of the associated ions.

Magistad (42) and Hoagland (26) reported that absorption of ions by plants is usually against a gradient. "From the standpoint of gradients a cell can more easily absorb the essential ions from saline solutions than non-saline because the gradient is less" (42). The work of transporting ions against a gradient comes from the oxidation of carbohydrates in the presence of oxygen.

Veihmeyer and co-workers (63) concluded that as long as the soil moisture was between the wilting percentage and the field capacity, plant growth or yield of fruit would not be affected. From an experiment with kidney beans on an artificially salinized soil where irrigations were made at moisture tensions of 250, 750, and over 800 centimeters of water, Ayers, et al. (4) found that bean growth and yield were reduced as the soil moisture tension at time of irrigation increased. Additions of sodium chloride decreased growth as the concentrations increased. Relative growth decreases were greater with sodium chloride where the moisture tensions at irrigation time were higher. They concluded that since plants must use more energy to obtain moisture at higher stresses, that energy goes for absorption and growth is restricted.

In summary, salt in soil affects plants directly, through osmotic pressure and toxicity and indirectly, through the adverse effects of the salt on soil structure and aeration. The effects on the plant are retardation of water uptake and ion absorption with resultant restriction of plant growth. Some of the ions may be toxic under certain conditions and upset the physiological functions in the plant. The stress by which water is held in the soil is made up of osmotic pressure and the attraction of the water and the soil particles. As the soil dries out, both forces increase in magnitude until the wilting point (about 15 atmospheres) is reached, beyond which plants cannot live. Saline soils may, under certain conditions, not furnish adequate aeration to plant roots, and growth is inhibited.

How copper affects plant growth in the soil

Comparatively little work has been reported on the functions of copper in the soil. Willis (65) stated the beneficial effects of copper have been attributed to (a) a simple nutritive function on the assumption that organic matter makes it unavailable to plants, (b) neutralization of toxic compounds formed in the soil, and (c) catalytic oxidation.

Copper is fixed by the organic matter in the soil, and is for that reason most commonly deficient in organic soils. Hasler (22) reported that the affinity of bivalent cations for humus-rich soil is as follows in increasing order: Cd, Hg, Ca, Ba, Mn, Zn, Co, Ni, Cu, and Pb. Except for lead, copper has the greatest affinity for organic matter. Smit (58) reported that the availability of copper is diminished by reducing and improved by oxidizing conditions.

Willis and Piland (66) stated that copper probably acts as a catalyst of the oxidation-reduction reactions in the soil. They added that "copper serves as a soil amendment, decreasing the availability of iron and possibly manganese. The effect may be favorable or not depending upon the oxidation intensity of the iron and manganese content of the soil." Willis (65) stated that soluble phosphorus added to a copper-deficient soil promotes the reduction of nitrogen. The addition of ferric oxide retards the denitrification process and promotes the fixation of phosphorus. Rapid phosphorus fixation may indicate reductive soil conditions. Willis suggested that in these soils where the application of phosphorus produces no response, the application of copper should correct the condition, by acting as an oxidizing agent.

Arnon (3) in a study of the relative merits of nitrate and ammonia nitrogen as sources of nitrogen for plants found that the addition of 0.5 parts per million of copper to the culture solutions increased growth in each case. Where copper was added to the aerated ammonia-treated culture, the increase in growth was more than 400 per cent over the non-aerated with no copper. These results suggest an oxidation function.

Lazarev (32) reported that experiments indicate that copper acts as an oxidizing agent in peat to oxidize such substances as ferrous iron and manganous manganese. He found that plants growing on soils treated with hydrogen peroxide did not respond to copper.

Besides its function as a catalyst and oxidizing agent, other possible functions have been reported. On a heather moor soil, Arnd and Segeberg (2) found that when the soil became dry, the plants suffered severe drought, a condition which appeared suddenly in hot weather. This disorder, called "cultivation sickness", was probably due to a closing of the capillaries. The authors found that copper could correct the condition. They suggested that copper may act as a coagulating agent or it may as a copper humate facilitate wetting and the passage of water. Copper deficiency on the soil was disputed.

Effront (11) found that a very dilute solution of copper sulfate stimulated germination. Unpublished reports at the Utah Agricultural Experiment Station indicate that copper may aid in germination on salty soils.

The utilization of ammonia, phosphorus, and potash by oat plants in pots was increased by adding copper to the soil (57).

Waksman and Johnstone (64) as has been mentioned, obtained first a depression then later a stimulation from the application of copper salts to bacterial cultures in a sea water media.

Possible roles of copper sulfate in a salty soil

Although little has been written on the role of copper in salty soils, several possibilities of a beneficial effect from copper may be deduced from the literature cited:

1. As a result of the unfavorable conditions of aeration in many salty soils, especially of the heavier types, applications of copper sulfate may produce beneficial effects through serving as an oxidizing agent or through catalyzing the oxidation-reduction reactions in the soil.

2. Although they were not working with a salty soil, the work of Arnd and Segeberg (2) suggests that copper may flocculate the soil colloids under certain conditions and facilitate the passage of water. This flocculating effect would also produce better aeration.

3. The discussion of Willis on podzolized soils (65), suggests that copper may produce beneficial effects by neutralizing toxic compounds formed in salty soils.

4. Unpublished reports at the Utah Agricultural Experiment Station as well as a report by Effront (11) suggest that copper may aid in germination in salty soils.

5. The results of Lipman and Gericke (34) as well as the numerous examples of antagonism suggest that copper may serve as an antagonistic agent in salty soils. Salt effects in soils certainly cannot be explained entirely by osmosis and its effects on the total moisture stress in the soil. Just how this antagonism could take place is a matter of conjecture. The copper may prevent the uptake of certain toxic ions by the plant, or it may, owing to the ease with which it is absorbed on the soil colloids, release other ions such as calcium which would inhibit the uptake of toxic ions.

On the strength of these possibilities, the experiments reported below were conducted to study the response of crops to the applications of copper sulfate on salty soils.

EXPERIMENTAL

Greenhouse pot experiment

In an effort to determine whether an antagonism can be produced in salty soils between sodium chloride and copper sulfate, and to determine whether the antagonism is specific for the copper ion or the sulfate ion, a pot experiment was set up in the greenhouse. Three soils were used: Millville loam, taken from the Experiment Farm at North Logan; a loam soil taken from a peach orchard on the bench southeast of Providence; and a clay loam soil from the Horticultural Farm at North Ogden. Millville loam is a highly calcareous soil derived from dolomitic limestone and has a pH of 7.86. The Providence soil is moderately calcareous and has a pH of 7.40. The soil from North Ogden has a pH of 7.40 and is slightly calcareous. Analyses on the three soils were run as outlined in the "Laboratory Manual for Soil and Plant Relations, Agronomy 155". The results of the analyses appear in table 1.

The three soils were fertilized with 1000 pounds per acre of 16-20-0 fertilizer and 320 pounds per acre of muriate of potash and were artificially salinized with 0.4 per cent of sodium chloride. Portions of each soil were treated as follows:

Treatments	Pounds per acre
Control	None
Copper sulfate	500
Copper sulfate	1000
Sodium sulfate	285
Sodium sulfate	570
Zinc sulfate	540
Zinc sulfate	1080
Calcium sulfate	345
Calcium sulfate	690
Ferrous sulfate	550
Ferrous sulfate	1100
Cupric chloride	342
Cupric chloride	684

Treatments	Pounds per acre
Cuprous chloride	200
Cuprous chloride	400
Copper acetate	400
Copper acetate	800
Copper nitrate	484
Copper nitrate	968

The treatments supply the same equivalent weights of each salt to the same weight of soil. Each treatment was replicated four times making a total of 228 pots in all. Two crops were grown in succession. A crop of tomatoes was planted January 24-25, 1947, by placing the seeds on the soil surface and covering with sand. As soon as the plants were of sufficient size, they were thinned to 5 per pot. The soil in the pots was brought to field capacity in moisture at frequent intervals by weighing and adding water to bring to the calculated values.

Table 1. Analyses of soils used in greenhouse pot experiments

Analysis	Soils Millville loam	Providence loam	North Ogden clay loam
Moisture equivalent, per cent	19.8	19.0	23.6
Saturated extract			
(Conductivity in micromhos/cm.)	1120.0	2100.0	800.0
Calcium carbonate, per cent	47.75	12.52	4.22
Base exchange capacity,			
(meq./100 gm. soil)	11.06	16.59	32.24
Exchangeable K, meq./100 gm. soil	1.38	3.35	1.31
Exchangeable Ca - Mg, "	9.68	13.24	30.93
Organic matter, per cent	2.67	3.33	6.72
Available K, parts per million	294.0	550.0	636.0
Phosphorus (acetate sol.) p. p. m.	12.3	32.5	6.25
Soil reaction			
pH saturated paste	7.86	7.40	7.40
pH 10:1 suspension	8.21	7.90	7.70

When the larger plants reached the bloom stage, the tops were harvested (March 31 to April 1, 1947) and weighed. Oven-dry weights of plants appear in table 2.

Following the tomato crop, the soil was emptied out of each pot, the roots removed, the soil replaced in the pot, and velvon barley was planted April 5, 1947. As soon as the plants were of sufficient size, they were thinned to 8 per pot. The soils were brought to field capacity in moisture at frequent intervals. When most of the barley was headed out, the crop was harvested (June 11-13, 1947). Yield data appear in table 3.

The weights of the tomato and barley plants were extremely variable throughout all the treatments and within the pots treated alike. The plant weight data in tables 2 and 3 fail to indicate any definite response to treatments of copper or other salts. With the tomato plants, the average weight on the treated soils is 6.12 grams per pot in comparison with 5.82 grams per pot for the untreated. Average plant weights on high and low applications of salts show no difference between the two levels as an average for all the different salts. Barley plant weights were not as variable as the tomatoes, but here again no response to treatments is apparent. The average weights for treated pots is 6.54 grams per pot as compared with 6.86 grams per pot for the untreated. The soils receiving the higher applications of salts produced an average of 7.00 grams per pot as compared with 6.07 grams per pot for the low applications, but this difference is not significant.

Field experiments

Two field experiments were established, one at the Eugene Perry

Table 2. Yield of tomato plants in three artificially salinized soils in relation to various treatments. (Dry weight in grams, average of four replications, in greenhouse pots)

Treatment		Soils used*				
		Millville	Providence	North Ogden	Average	Relative yields
Lbs/acre						
None		4.86	6.33	6.28	5.82	100.0
$CuSO_4$	500	2.29	2.68	3.57	2.85	48.9
$CuSO_4$	1000	8.20	2.56	11.48	7.41	127.3
Na_2SO_4	285	8.97	4.49	6.77	6.74	115.8
Na_2SO_4	570	1.56	5.98	8.31	5.28	90.7
$ZnSO_4$	540	2.12	1.32	2.72	2.05	35.3
$ZnSO_4$	1080	2.23	4.87	4.73	3.94	67.7
$CaSO_4$	345	3.02	11.32	6.53	6.96	119.5
$CaSO_4$	690	3.29	1.86	9.51	4.89	83.9
$FeSO_4$	550	4.80	5.21	18.10	9.37	160.9
$FeSO_4$	1100	1.51	7.76	8.86	6.04	103.8
$CuCl_2$	342	1.86	2.56	3.94	2.78	47.8
$CuCl_2$	684	3.42	2.90	6.51	4.28	93.5
CuCl	200	3.29	11.42	8.63	7.78	133.6
CuCl	400	2.51	4.05	8.52	5.02	86.3
$CuAc_2$	400	2.58	9.40	17.47	9.82	168.6
$CuAc_2$	800	8.52	6.61	14.72	9.95	170.9
$Cu(NO_3)_2$	484	1.35	6.19	10.26	6.77	101.9
$Cu(NO_3)_2$	968	4.28	9.15	11.28	8.24	141.5
Average		3.72	5.61	8.85		

*Soils salinized with 0.4 per cent NaCl

Analysis of Variance

Source of variation	D. F.	Sums of squares	Mean square	F
Total	227	9,920.83		
Between soils	2	1,024.16	512.08	13.45**
Between treatments	18	1,185.93	65.89	1.73*
Treatment x soil	36	1,262.37	35.07	---
Between replicates	3	41.68	13.89	---
Error	168			

Least significant difference between treatment means @ .05 = 4.97

Table 3. Yield of barley plants in three artificially salinized soils in relation to various treatments. (Dry weight in grams, average of four replications, in greenhouse pots)

Treatment		Soils used*				
		Millville	Providence	North Ogden	Average	Relative yields
Lbs/acre						
None		9.67	6.11	4.82	6.86	100.0
$CuSO_4$	500	10.02	5.10	4.58	6.56	95.6
$CuSO_4$	1000	9.33	7.84	6.06	7.74	112.8
Na_2SO_4	285	9.88	5.08	3.13	6.03	87.8
Na_2SO_4	570	8.94	5.17	7.32	7.14	104.1
$ZnSO_4$	540	7.18	3.23	3.17	4.53	66.0
$ZnSO_4$	1080	8.90	4.40	5.24	6.18	90.0
$CaSO_4$	345	8.35	6.54	5.35	6.75	98.3
$CaSO_4$	690	7.58	3.79	7.39	6.25	91.1
$FeSO_4$	550	8.12	5.10	8.02	7.08	103.1
$FeSO_4$	1100	9.89	4.07	6.21	6.72	97.9
$CuCl_2$	342	7.21	3.38	5.02	5.21	75.8
$CuCl_2$	684	8.78	3.33	5.27	5.79	84.4
$CuCl$	200	6.57	7.11	4.32	6.00	87.5
$CuCl$	400	9.87	6.30	5.19	7.12	103.7
$CuAc_2$	400	7.19	3.48	6.49	5.72	83.3
$CuAc_2$	800	10.88	6.10	8.79	8.59	125.1
$Cu(NO_3)_2$	484	8.05	5.30	6.98	6.77	98.7
$Cu(NO_3)_2$	968	7.38	5.72	9.36	7.48	109.0
Averages		8.62	5.11	5.98		

*Soils salinized with 0.4 per cent NaCl

Analysis of Variance

Source of variation	D. F.	Sums of squares	Mean square	F
Total	227	2550.24		
Between soils	2	511.88	255.94	36.91**
Between treatments	18	187.05	10.39	1.50
Treatment x soil	36	268.19	7.45	1.07
Between replicates	3	218.18	72.73	10.49**
Error	168	1164.95	6.93	

Farm, Perry, and the other on the Leon Anderson Farm, Tremonton. On both farms the soils were moderately saline and of clay loam texture. The pH values of the Perry and Anderson farm soils were respectively 8.7 and 8.0. Eight treatments were applied and replicated four times on thirty-two, 12' x 50' -plots on each field. The treatments were as follows:

Treatment--Lbs/acre

Control
Copper sulfate, 50
Copper sulfate, 100
Copper sulfate, 250
16-20-0 fertilizer, 350
16-20-0 fertilizer, 350, plus copper sulfate, 50
16-20-0 fertilizer, 350, plus copper sulfate, 100
16-20-0 fertilizer, 350, plus copper sulfate, 250

The plots were planted to barley in the early spring and were managed by the farm operators according to common farm practices. At harvest time three, square-yard quadrats were cut from each plot. The quadrat samples were combined for threshing and yield records. Yield data on these two field experiments appear in table 4. Soil samples were taken and analyzed for carbon dioxide soluble phosphorus, calcium carbonate, organic matter, conductivity of saturated extract, and pH. Results of the analyses appear in table 5.

The yield data, table 4, fail to show any response to the application of copper sulfate. However, there were significant increases in yields of threshed grain on the plots treated with 16-20-0 fertilizer. An examination of the average yields on the Anderson farm on the plots receiving no 16-20-0 fertilizer shows a small increase in yield with copper applications up to the 250-pound application, at which point a reduction in yield occurred. Since this trend was not repeated

Table 4. The yield of barley on two farms in relation to copper and fertilizer treatment. (Yields of grain in bushels per acre)

Eugene Perry Farm, Perry

Treatments Lbs/acre CuSO$_4$	16-20-0	Replications 1	2	3	4	Average	Relative yields*
0	0	60.76	75.58	54.09	65.58	65.00	95.5
50	0	47.42	60.39	44.46	76.32	57.15	85.4
100	0	63.73	63.36	59.65	46.31	58.26	87.0
250	0	70.99	74.47	41.35	57.80	61.15	91.4
0	350	75.21	104.85	84.47	56.69	80.31	120.0
50	350	103.37	84.47	77.81	64.84	82.62	123.5
100	350	101.15	65.58	73.73	78.55	79.75	119.0
250	350	62.32	82.99	64.84	74.47	71.15	106.2
Average		73.12	76.46	62.55	65.07	69.30	103.4

Leon Anderson Farm, Tremonton

Treatments Lbs/acre CuSO$_4$	16-20-0	Replications 1	2	3	4	Average	Relative yields*
0	0	55.95	62.24	58.54	54.69	57.85	86.4
50	0	64.10	47.79	71.14	53.57	59.15	88.3
100	0	58.91	55.58	61.87	69.28	61.41	91.6
250	0	60.02	40.76	59.65	62.24	55.67	83.2
0	350	85.22	74.10	68.91	60.39	72.15	106.2
50	350	72.62	60.76	72.99	63.50	67.47	100.5
100	350	73.36	64.47	70.02	71.51	69.84	104.2
200	350	72.99	64.84	78.18	79.29	73.82	110.1
Average		67.90	58.82	67.66	64.31	64.67	96.5

*Average yield (66.99 bu/acre) taken as 100

Analysis of Variance
(Table 4)

Source of variation	D. F.	Sums of squares	Mean square	F
Total	63	10,894.93		
Between treatments	7	3,849.18	549.88	5.41**
Copper levels	3	82.54	27.51	---
Fertilizer levels	1	3,750.03	3,750.03	36.87**
Fertilizer x copper	3	16.61	5.54	---
Between farms	1	342.81	342.81	3.37
Soil effects	6	1,807.35	301.23	2.96*
Treatment x farm	7	623.74	89.11	---
Error	42	4,271.85	101.71	

Least significant difference between treatments:
@ .05 = 10.19
@ .01 = 13.63

Table 5. Analyses on soils from field plots at Tremonton, Perry, and North Ogden. (Average of several determinations on topsoils)

Soils	Saturated extract	Phosphorus (CO_2 soluble)	Soil Reaction	Calcium Carbonate	Organic Matter
0-12"	Conductivity micromhos/cm.	p.p.m.	pH	percent	percent
Perry clay loam	1170	4.40	8.70	20.15	6.14
Anderson clay loam	3470	2.66	8.00	9.32	3.64
North Ogden clay loam	510	9.10	7.56	11.74	7.02

in the plots treated with 16-20-0 fertilizer and on any of the plots on the Perry farm, the variation in yields can be attributed to factors other than copper treatment.

Artificially salinized plot experiment

An artificially salinized plot experiment was established at the North Ogden Horticultural Farm. Five plots (14' x 14') were leveled by throwing aside the topsoil, leveling the subsoil, and then replacing the topsoil. The soil in the plots was treated as follows:

Plots 5 and 8	200 lbs/acre copper sulfate broadcast, 50 lbs/acre side-dressed
Plot 6	50 lbs/acre copper sulfate side-dressed
Plots 7 and 9	no copper

Each plot received 1 pound of treble superphosphate.

The plots were planted to Buffalo alfalfa, California Common alfalfa, Velvon barley, Winter Club barley, Overland oats, Federation wheat, and Lemhi wheat. The plantings were made in seven rows and seven columns, with each variety occurring in each of the columns and rows. The alfalfa plantings were made by placing two young plants 11 inches apart. The grains were sown in 18-inch rows and thinned to 18 plants per row when the grain was about 1 inch high. There were 7 inches between alfalfa and grain and 4 inches between different grain crops. The two varieties of alfalfa were not planted adjacent to each other.

Moisture tension was measured with tensiometers placed at a 12-inch depth in the soil in each plot. All plots were watered with 8-inch irrigations when the soil moisture tension reached 600 centimeters of water. All irrigation water was salinized with 2500 parts per million of calcium chloride and 2500 parts per million of sodium chloride.

Samples were taken from the first, second and third foot of soil in each plot one week after each irrigation. Conductivity was run on 1:1 extracts of all the samples.

The alfalfa was harvested in late bloom stage, and the grains were allowed to reach maturity before harvesting. Dry weights of alfalfa plants and threshed grain weights appear in table 6.

Table 6. Average yields of alfalfa plants and threshed grain grown at North Ogden on artificially salinized plots in relation to treatments with copper sulfate. (Dry weight in grams, average per plot)

Crops	Treatments Copper sulfate--lbs/acre					
	0	0	50	250	250	Average
Buffalo alfalfa	83.9	86.1	101.3	111.1	71.2	90.7
Cal. Common alfalfa	83.0	60.1	90.4	106.7	127.2	89.5
Velvon barley	101.0	113.8	86.4	112.1	120.6	106.8
Winter Club barley	47.4	85.3	51.4	53.6	80.7	63.7
Overland oats	57.1	111.7	56.6	87.7	89.1	80.4
Federation wheat	53.1	63.6	56.1	70.0	65.6	61.7
Lemhi wheat	44.9	40.8	41.7	74.9	64.9	53.4
Average	64.3	80.2	69.1	88.0	88.5	
Relative yield*	89.0	111.0	95.6	121.8	122.5	

Average no copper -- 72.25
Average 50 lbs copper -- 69.10
Average 250 lbs copper -- 88.25

*Average no copper (72.25) taken as 100.0

In order to determine whether copper sulfate affected the uptake of ions by the plants, the grains were analyzed for chlorine, sodium, and calcium. The results of these analyses appear in table 7.

Table 7. The mineral content of grains grown in field plots at North Ogden in an artificially salinized soil as influenced by copper sulfate applications.

Copper sulfate Lbs/acre	Grains				
	Velvon barley	Winter Club barley	Overland oats	Federation wheat	Lemhi wheat
			Per cent Chlorine		
0	.051	.057	.071	.035	.031
50	.046	.046	.059	.025	.046
250	.050	.049	.070	.038	.039
			Per cent Calcium		
0	.042	.037	.087	.032	.048
50	.057	.043	.090	.037	.042
250	.052	.065	.110	.034	.045
			Per cent Sodium		
0	.039	.034	.059	.014	.017
50	.023	.040	.060	.012	.014
250	.030	.046	.058	.011	.020

Analyses on the soil appear in table 5.

Average yields of the crops, as shown in table 6, on each plot show a small though inconsistent response from the 250-pound per acre application of copper sulfate; but the 50-pound application of copper sulfate resulted in no benefit to the plants. The reliability of the results is not as good as hoped for owing to the loss of part of the plants on plot 9 by gophers. The highest average yields of Winter Club barley and Overland oats were obtained on plot 9 where no copper was applied. California Common alfalfa showed an increase in yield with rate of copper application, but this trend was not repeated in the

Buffalo alfalfa, where the lowest average yield occurred in plot 8 which was treated with 250 pounds per acre of copper sulfate. The differences in average yields when compared with the variation within and between plots would seem to indicate little, if any, response to copper applications.

As reflected in the mineral content of the plant tissue, table 7, copper sulfate did not appreciably affect the uptake of ions by the plants.

<u>Greenhouse solution culture experiment</u>

In order to determine whether an antagonism can be produced between copper and sodium chloride in solution, a solution culture experiment was set up in the greenhouse using two levels of added copper and 3 levels of sodium chloride. The following basal nutrient solution was used: calcium nitrate 0.821 grams, potassium nitrate 0.506 grams, KH_2PO_4 .136 grams, magnesium sulfate 0.120 grams, and 1 liter of water. To each liter of basal solution was added 1 ml. of a solution consisting of 0.389 grams of $MnCl_2.4H_2O$, 0.0666 grams zinc sulfate, 0.611 grams boric acid, and 1 liter of water, and 1 ml. of a 0.5 per cent solution of ferric citrate. The solutions were made up using Logan City water, which contains sufficient copper for normal growth in solutions. Sodium chloride was added to the basal solutions at rates of 1000, 3000, and 5000 parts per million, and copper was added at rates of 0.5 and 1.0 part per million. All treatments and the control were replicated four times.

Dwarf Alderman garden peas were grown in the solutions in glass tumblers of approximately 300 ml. size. The solutions were changed at frequent intervals throughout the duration of the experiment. The peas were sprouted on crockery plates and transferred to the solutions when the seedling roots were one-half to one inch in length. After approximately six-weeks growth, the peas were harvested. Weights of both tops and roots were recorded.

Of all the experiments reported in this paper, the solution cultures produced probably the most consistent results. Growth reduction in the peas was linear with concentration of sodium chloride in the solution. This is shown in tables 8 and 9 on yield data and graphically in figure 1. The most striking result was the toxicity (a yellowing of the terminal leaves) produced by the small concentrations of added copper. This yellowing in the leaves appeared first when the plants were about one month old, particularly in the copper-treated cultures containing no sodium chloride and in those containing only 1000 parts per million of the salt. As the plants became older, those in the copper-treated cultures containing 3000 parts per million of sodium chloride produced terminal leaves which were yellow in color. In the more severe cases of toxicity, the terminal leaves were almost white. The higher concentrations of sodium chloride appeared to postpone the yellowing to a considerable extent, as evidenced by the fact that the terminal leaves of the plants in the solutions containing 5000 parts per million of salt were not yellow at harvest time. The prolongation of the experiment may have eventually produced copper toxicity in the highest salt concentration.

The yield data, tables 8 and 9, show that without exception as the sodium chloride concentration in the solutions increased,

Table 8. Weight of pea plants grown in solution cultures in relation to treatments with sodium chloride and copper sulfate. Average dry weight (grams per culture) of tops

Sodium chloride p.p.m.	Copper added to solution culture p.p.m. 0	0.5	1.0	Average weight	Relative yield (NaCl)
None	1.58	1.31	1.38	1.42	100.0
1000	1.20	0.97	1.16	1.11	78.1
3000	0.88	0.72	0.79	0.80	56.1
5000	0.48	0.52	0.51	0.50	35.4
Average	1.04	0.92	0.96		
Relative yield (Cu)	100.0	85.0	92.9		

Analysis of Variance

Source of variation	D. F.	Sums of squares	Mean square	F
Total	47	9.39		
Between levels NaCl	3	5.66	1.89	19.29**
Between levels copper	2	0.21	0.11	1.12
NaCl x copper	6	0.14	0.02	----
Between blocks	3	0.13	0.04	----
Error	33	3.25	0.098	

Least significant difference between levels NaCl
@ .05 = 0.26, @ .01 = 0.35

Table 9. Weight of pea plants grown in solution cultures in relation to treatments with sodium chloride and copper sulfate. Average dry weight (grams per culture) of roots

Sodium chloride p.p.m.	Copper added to solution culture p.p.m. 0	0.5	1.0	Average weight	Relative yield (NaCl)
None	0.51	0.50	0.60	0.54	100.0
1000	0.47	0.41	0.53	0.47	87.3
3000	0.35	0.40	0.42	0.39	71.9
5000	0.22	0.26	0.39	0.26	48.2
Average	0.388	0.392	0.460		
Relative yield (Cu)	100.0	101.6	119.3		

Analysis of Variance

Source of variation	D. F.	Sums of squares	Mean square	F
Total	47	1.1955		
Between levels NaCl	3	.5215	.1738	9.82**
Between levels copper	2	.0549	.0275	1.55
NaCl x copper	6	.0215	.0036	----
Between blocks	3	.0120	.0040	----
Error	33	.5856	.0177	

Least significant difference between levels NaCl
@ .05 = 0.11, @ .01 = 0.15

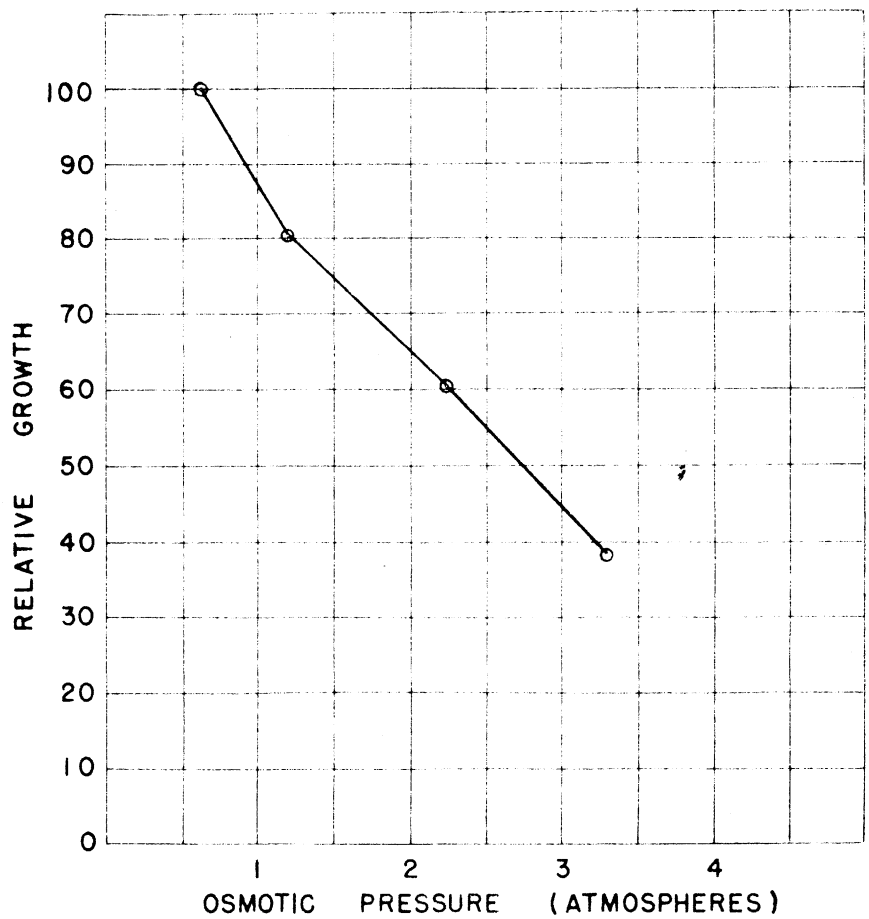

FIGURE 1. RELATIVE GROWTH OF PEA PLANTS IN SOLUTION CULTURES AS RELATED TO THE OSMOTIC PRESSURE IN THE SUBSTRATE

the average weight of tops and roots decreased. In general, especially in the tops, the copper-treated solutions yielded less than those without copper. However, in the higher salt concentrations, the copper-treated solutions yielded slightly more than the no copper cultures. This is more noticeable in the yields of roots, table 9. In both tops and roots, the higher copper treatment produced consistently higher yields than the lower treatment, however, the differences are not wide enough to be significant.

DISCUSSION

Owing to the negative nature of the results obtained in the experiments reported in this paper, the discussion which follows suggests reasons why copper sulfate failed to produce increased growth under the conditions of the experiments.

In the soils of this area which have been studied, no copper deficiency is apparent. The soils used in this investigation also support this view. Even though responses were reported at Brigham Young University and at Magna (19), (20), the responses were so small that on the basis of the natural variability in similar tests elsewhere the differences attributed to copper would not be statistically significant.

Copper may serve as a catalyst and oxidizing agent in the soil (3)(32)(65)(66), but the factors required to produce response in a salty soil are undoubtedly beyond the scope of catalysis and oxidation by copper. When a soil lacks aeration, oxygen is the element required.

Owing to its occurrence in such small quantities in the soil, (15) copper probably cannot have any appreciable flocculating effect on the soil colloids and therefore would not affect the soil structure.

Although the neutralization of toxic compounds in soils has been attributed to copper (65), especially in organic soils, such toxins affected by copper may not occur in salty, mineral soils.

In order for an ion to function as an antagonistic agent, several conditions are usually required. The ion must be in comparable concentration with the ion or ions to be antagonized (28)(49)(50). The medium in which antagonism occurs is generally comparably concentrated. As far as copper is concerned, these conditions cannot be met. In the first place, copper occurs in very small amounts in the soil. When copper is applied, it is immediately tied up either by the soil colloids, or by the organic matter, or it is precipitated as copper carbonate or other insoluble compounds. These factors make the concentration of copper relatively low when compared with other ions. In the second place, if copper were to be added to the soil in sufficient quantity to give a soil solution concentration comparable with sodium chloride, the copper would be so toxic that plant growth would cease. In addition, the cost of the application of copper in large amounts to the soil is prohibitive.

Other factors which contributed to the nature of the results of the experiments may be pointed out. Moisture control in pots is very difficult. The top soil in the pot may be too wet while the lower soil is lacking in moisture. This uneven distribution of moisture also results in uneven distribution of salts. As a consequence, plant growth is extremely variable. These factors probably obscured any possible results that may have otherwise resulted from the different salt treatments. However, if the salt treatments had produced any appreciable effect, the responses would undoubtedly have been evident in spite of the salt and moisture factors.

The results of the experiment at North Ogden on the artificially salinized plots suggest that with a more refined experiment small benefit from the application of copper sulfate to a salty soil might possibly be more conclusively demonstrated. However, the response would probably be so small that the added expense of the copper sulfate applied would not be justified.

The field experiments at Tremonton and Perry support the view that copper sulfate is ineffective in producing increased yields in the salty inorganic soils of Western United States. The solution culture trial verified the fact that copper becomes toxic in minute concentrations in solution. In addition, the copper apparently had no antagonistic effect on the sodium chloride, but sodium did reduce copper toxicity.

Analyses of the grain from the plots at North Ogden indicate that copper had no effect on the uptake of calcium, sodium and chlorine by the plant. Calcium, sodium, and chlorine occur in such small concentrations in the grains (0.01% to 0.15%) that the measurement of any differential uptake by the plants is extremely difficult. The problem is further complicated by the fact that there is considerable variation in mineral content within the same variety of grain (14). Owing to these factors, grain is probably not as satisfactory to use in the study of nutrient uptake as other parts of the plant.

<u>Suggestions for additional work on the problem</u>

Any additional work with copper in relation to plant growth in salty soils could include the following:

1. Since a small average increase in yield was obtained on the plots at North Ogden, a similar experiment could be improved through the addition of other salt treatments, several levels of treatment, and an increase in number of replications.

2. Work with solution cultures could include the application of higher levels of both copper and sodium chloride. This is suggested by the fact that the higher copper level tended to produce more growth than the lower level.

3. Trials on more concentrated salty soil areas may prove beneficial.

From previous work at the Utah State Agricultural College, probably the most promising study is the effect of copper salts on germination. This problem should be explored.

SUMMARY AND CONCLUSIONS

The research included in this problem was planned to investigate the value of copper sulfate in the production of increased yields of crop plants on salty soils. The work included a pot experiment in the greenhouse, three field studies, and one solution culture experiment.

1. Tomatoes and barley were grown in succession in pots containing three artificially salinized soils (Millville loam, a loam soil from Providence, and a clay loam soil from North Ogden) treated variously with two levels of nine different salts. No response to treatment was apparent. The inadequate control of moisture in the pots with resultant uneven distribution of salt in the soil resulted in extreme variation in growth. These factors probably obscured any response to salt treatment which may have otherwise been obvious.

2. In two field plot experiments, naturally saline soils planted to barley were treated with three levels of copper sulfate with and without 16-20-0 fertilizer. Significant response was obtained from the 16-20-0 fertilizer, but the copper sulfate gave no increase in yields. The results indicate that copper sulfate is ineffective in producing increased yields in the salty inorganic soils of Western United States.

3. At the Horticultural Farm, North Ogden, Buffalo alfalfa, California Common alfalfa, Velvon barley, Winter Club barley, Overland oats, Federation wheat, and Lemhi wheat were planted in artificially-salinized plots, treated with 0, 50, and 250 pounds of copper sulfate per acre. A small, but inconsistent increase in yield was obtained from the higher copper sulfate application, but the lower application gave no response. The results suggest that with a more refined experiment small benefit from the application of copper sulfate to a salty soil might possibly be more conclusively demonstrated.

4. Analyses of the threshed grain from the North Ogden plots failed to show that copper had any effect on the uptake of calcium, sodium, or chlorine by the plants. The very small concentrations of the elements in the grain make the detection of any change in nutrient uptake difficult.

5. Dwarf Alderman garden peas were grown in the greenhouse in solution cultures containing 0.5 and 1.0 parts per million of copper and 1000, 3000, and 5000 parts per million of sodium chloride. Dry weights of both tops and roots showed a linear relationship between growth reduction and salt content in the substrate. The copper produced a yellowing in the terminal leaves of the peas after the first

month of growth in all the copper-treated cultures except those containing the highest concentration of sodium chloride. The copper-treated cultures averaged less in yield than those not treated. The copper apparently had no antagonistic effect on the sodium chloride, but the sodium did reduce the copper toxicity.

6. The results of the experiments reported indicate that the application of copper sulfate to salty soils not deficient in copper will produce little, if any, crop response. Antagonism in salty soils is not as dominant a factor in plant growth as is osmotic pressure.

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